Boundary Current and Mixing Processes in the High Latitude Oceans

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Grant Number: N00014-03-1-0067
http://www.esr.org

LONG-TERM GOALS

The overarching goal of this project is to expand our understanding of the dynamics and distribution of mixing in the global ocean. This project extends to smaller scales the past high latitude ocean research carried out by the investigator and incorporates a desire to integrate high latitude results into the global ocean context. Improved qualitative and quantitative understanding is needed if we are to improve our ability to incorporate mixing processes into large-scale models, and this need has provided a primary driver for this project. The work emphasizes high latitude oceans because: (1) they are primary sites for surface conditioning of deep waters that drive the meridional overturning circulation, a significant component of the overall mean ocean circulation and one that is particularly sensitive to mixing processes; (2) they provide some excellent, and in some cases extreme, examples of mixing-related phenomena that are active throughout the world oceans and therefore can broaden our parameter spectrum for such phenomena; (3) they provide highly suitable, and in some cases excellent, natural laboratories for field study of these phenomena; and (4) the high latitude oceans are data-poor in comparison with the rest of the global ocean, despite the apparent importance of understanding mixing processes in these remote areas.

OBJECTIVES

The following specific objectives contribute to the above goal:

- Document deep high latitude boundary currents and density flows, quantitatively determine the associated mixing processes, and assess their impact on regional and basinwide mixing and water mass modification;
- Document and quantify the generation at high latitude ocean boundaries of mixing-related, small-scale features such as tidally-driven internal waves and double-diffusive interleaving, and assess their impact on adjacent basin waters;
- Acquire quantitative, field-based information on seawater equation-of-state processes, such as double-diffusion, cabelling and thermobaric instability, that are anticipated to play significant roles at high latitudes where temperatures are low and static stability is often exceedingly weak; and,
- Actively coordinate, through participation in working groups and conferences, these field-based efforts with those being carried out elsewhere and with parallel large-scale modeling efforts. A significant portion of this coordination effort will take place through the efforts of IAPSO/SCOR Working Group 121 on Ocean Mixing, of which Robin Muench is Chair.

APPROACH

Quantitative data will be obtained, using the most state-of-the-art methods reasonably available for a given effort, on mesoscale to microscale physical oceanographic processes from specific high latitude ocean sites. Measurement systems that have been, or will be, available include various models of conductivity-temperature-depth profiling (CTD) systems, lowered and vessel-mounted acoustic Doppler current profiler (ADCP) systems, and both tethered free-fall and CTD-mounted profilers for microstructure temperature and conductivity profiles and (in the case of tethered free-fall systems only) vertical current shear profiles. These field efforts will utilize platforms available primarily under the auspices of other funded programs, including NSF projects and those funded and operated by foreign institutions. Study sites have been selected for their suitability for use in this work because they provide a diverse set of environments. Not incidentally, they are anticipated to provide suitable archetypes for turbulent processes that are active throughout the global ocean. Such processes include density flows such as that exiting from the Ross Sea, equation-of-state driven phenomena such as prevail in the Maud Rise region of the Weddell Sea, and double-diffusive interleaving such as seen across the entire Arctic Ocean basin.

Derivation of quantitative information from the field data uses primarily existing methods that have been documented in the literature. One such method, that involving Thorpe displacements, can be applied to high quality CTD data and to microstructure profiler data in order to obtain estimates of turbulent parameters such as dissipation and vertical eddy viscosity [*Thorpe*, 1977; *Dillon*, 1982]. In other situations methods utilizing vertical current profiles, frequently derived using either hull-mounted or lowered acoustic Doppler current systems, in conjunction with CTD data are more suitable [*Polzin et al.*, 2002; *Muench et al.*, 2002]. In certain situations, doubtless, neither method will be appropriate. In such cases an ongoing collaboration with specialists in ocean mixing will be relied upon to seek solutions. In addition to informal exchange of ideas, a formal mechanism for collaboration exists in the form of IAPSO/SCOR Working Group 121 on Ocean Mixing, of which Robin Muench is Chair. Further information on this working group can be found through links on the SCOR home page at http://www.jhu.edu/scor/. Ocean mixing has recently undergone a resurgence of interest that has spurred new research, and the importance of professional networking among the interested parties cannot be overstated.

WORK COMPLETED

The end of the first year of this newly-funded project closes on a successful period in which some new field results have been obtained and plans have been laid for relevant future work. Some specific accomplishments:

- Managed, as Chief Scientist, oceanographic and sea ice research projects that were carried out from a drifting ice station – APLIS/ICEX – that took place in April 2003 near the base of the Beaufort Sea continental slope north of Prudhoe Bay, Alaska. This area is known to be a primary site for cross-slope transport of mass and dissolved materials, including shelf-formed dense water plumes, from the shelf into the central Arctic Ocean. Scientific tasks included acquisition of upper ocean hydrographic and current data adequate to assess offshore, upper ocean volume transports and associated vertical mixing during late winter. Management duties consisted of soliciting scientific participants, coordinating participation in the station field activity, and coordinating preparation of a post-exercise summary of the science activities;
- Shared in overseeing acquisition, under the auspices of the Arctic SBI program (see below "Related Projects"), of a high quality hydrographic and current dataset during July-August 2003 from

the Beaufort and Chukchi sea shelf-slope region. These data will be used in an attempt to assess turbulent structures associated with the shelf-slope boundary regime and associated density currents;

- Shared in the acquisition of vertical current profiles and microstructure T and C data adequate to assess dynamics and the turbulent mixing regime associated with the density flow of shelf water exiting the Ross Sea, Antarctica during February-April 2003. With current speeds exceeding 3 knots, and an instantaneous transport in excess of 2 Sv, this may be one of the largest and most energetic density flows from which we have obtained microstructure observations; and,
- Participated in several activities focused on coordinating and fostering studies of ocean turbulence in mixing away from the continental shelves. A major success was establishment of joint IAPSO/SCOR Working Group 121 on Ocean Mixing, which has among its goals the coordination of research efforts toward improvement of parameterization of turbulence in large-scale ocean models. Corollary efforts included co-convening (with Steve Thorpe and Eugene Morozov) a 3-day symposium on ocean mixing at the IUGG Assembly held in Sapporo, Japan in July 2003 and presenting and discussing turbulence issues at a joint meeting in Bremerhaven, Germany in September 2003. Firm plans have been laid for an international symposium on ocean mixing to take place in Victoria, Canada during October 2004. Information concerning Working Group 121 and its activities can be found on the SCOR website (http://www.jhu.edu/scor/).

RESULTS

In the northern high latitudes:

Observations obtained in April 2003 from the APLIS/ICEX ice station in the Beaufort Sea using a lowered acoustic Doppler profiler revealed presence of an eastward current jet with maximum speeds of about 7 cm/s near 100 m depth. This jet persisted for more than a week at the drifting site over the outermost continental slope. Roughly along-isobath at the station location, the eastward flow had apparently transported shelf-origin water from the shallow Chukchi Borderlands region to the west, an assessment borne out by concurrent radium isotope observations made by *Dave Kadko* (Univ. of Miami). This result demonstrates advective transport of shelf-derived waters into the central Arctic basin, where they help to maintain the halocline and thereby reduce vertical turbulence and upward heat flux, which might otherwise hasten the thinning of the Arctic ice cover. The mechanism(s) behind such jets are being investigated with an emphasis on the potential connection with the relatively energetic shelf break currents farther south. These winter data have been supplemented with a large set of similar current profiles obtained from the same region in July-August 2003 under the auspices of the SBI program (see "Related Projects" below). The July-August data reveal a rich field of mesoscale features that are associated with the shelf break and upper slope and that likely provide driving energy for turbulent processes. Ongoing work will use the combined datasets to evaluate mechanisms for mixing and will assess possible impacts of features such as the observed jet on the interior Arctic basin. Early results from this work have been submitted for presentation at the February 2004 ASLO/TOS Oceanography Conference in Honolulu, Hawaii.

At southern high latitudes:

A pioneering set of small-scale and microscale observations were obtained during February-April 2003, under the auspices of the AnSlope program (see "Related Projects" below), from the density flow of bottom water as it exits the Ross Sea. These observations were obtained in the most energetic portion of this flow, where it passes over the shelf break and flows down the steep upper slope. The flow was bottom-trapped, exceeded 200 m in thickness, and had associated speeds greater than 150 cm/s. Rough estimates based on flow speed and cross-sectional area suggest an instantaneous

transport exceeding 2 Sv, consistent with past estimates of the outflow of dense, shelf-modified bottom water from the Ross Sea.

The Ross Sea observations will allow an assessment of turbulent processes associated with this highly energetic plume. Observations included CTD-derived profiles of temperature and salinity, microstructure profiles of temperature and conductivity, and vertical current profiles derived from a lowered acoustic Doppler current profiler. Early computational results, derived using the method of Thorpe displacements applied to the temperature and conductivity profiles, suggest vertical eddy viscosities of order 10^{-1} to 10^{-2} m^2s^{-1} in the high-speed core. Viscosities computed by this method decreased by two orders of magnitude across the upper boundary of the density current, however, considerably more work needs to be done to ascertain whether these estimates are realistic. What seems certain is that diapycnal mixing is extremely vigorous within the core. More detailed conclusions await in-depth analyses of the data. Early results from this work are being submitted for presentation at the 2004 AGU Ocean Sciences Meeting in Portland, Oregon.

With respect to tidal forcing:
The case for tides playing a primary role in ocean mixing has recently been made in the literature [*Munk and Wunsch*, 1998]. Analytical results reported elsewhere have substantiated this case, and field research has begun to address this issue in mid-latitudes. It in fact appears from our field results that the ocean tides play a critical role in the process by which ventilation of Ross Sea shelf water into the deep ocean occurs, and we are submitting this work for presentation at the 2004 AGU Ocean Sciences Meeting. We are also investigating Antarctic shelf regions where mixing appears to be driven almost entirely by non-tidal shear (the southwestern Antarctic Peninsula, addressed under the GLOBEC program as summarized below under “Related Projects”) or by an equal mixture of tidal, inertial and mean shear (the western Weddell Sea, addressed under the ISPOL1 program as summarized under “Related Projects”).

IMPACT/APPLICATIONS

Our understanding of ocean mixing processes has generally lagged our grasp of the large-scale circulation. Perhaps the greatest impact of this knowledge gap has been the inability of large-scale ocean models to adequately parameterize these small-scale processes. This lack of adequate parameterization has in turn limited the ability of models to recreate all pertinent aspects of the large-scale circulation or to provide credible predictions of reaction to various climate change scenarios. Perhaps of most interest to Navy operational needs, *an inability to reliably predict long-term changes in such ocean parameters as stratification negatively impacts our ability to foresee changes in acoustic characteristics*. Recently, though, a number of elegant studies involving methods such as tracer releases and utilizing newly developed instrumentation have started to close the gap in understanding between the very large and the very small scale ocean processes. We are now acquiring a quantitative, as well as a qualitative, understanding of the interactions among mean and fluctuating currents (such as shelf edge vorticity waves and tides), internal waves, seafloor topography and roughness, stratification, and mixing. We are now at a point from whence we can see a rapid growth in our quantitative understanding of ocean mixing and in our ability to model the large-scale ocean. This project both acquires new basic information on ocean mixing and attempts to aid in the coordination of developments in these two areas so that we can obtain the greatest possible benefit to both, and to oceanography in general.

RELATED PROJECTS

SBI, An ongoing NSF-funded, multi-year study of Arctic Ocean Shelf-Break Interactions, addressing shelf-slope exchange and mesoscale and turbulent structures associated with density flows in the Beaufort and Chukchi seas of the western Arctic Ocean (http://sbi.utk.edu/).

AnSlope, an ongoing NSF-funded study of off-shelf flow of the dense bottom water plume that originates beneath the Ross Ice Shelf, Antarctica and contributes more than one quarter of the world ocean's Antarctic Bottom Water (http://www.ldeo.columbia.edu/physocean/anslope/).

Southern Ocean GLOBEC, an NSF-funded study of processes ranging in scale from regional down to turbulent mixing scales in Marguerite Bay, a deep, continental shelf embayment on the southwestern Antarctic Peninsula (http://globec.whoi.edu/jg/dir/globec/soglobec/).

ISPOL1, A scheduled, German-sponsored, late winter drift station aboard the German icebreaking research vessel *Polarstern* in the western Weddell Sea that will allow detailed documentation of the deep, density-driven western boundary flow and of the internal wave and mixing fields associated with the shelf break and upper slope (http://www.awi-bremerhaven.de/Climate/ISPOL/index.html).

Beringea 2005, A scheduled, primarily Swedish-sponsored, late summer trans-Arctic crossing by the Swedish research icebreaker *Oden* that will make possible for the first time the documentation of microscale features associated with the basin boundaries and of double-diffusive interleaving features that span the entire basin (http://www.polar.se/english/expeditions/beringia2005/index.html).

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